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TITLE: Avoiding Late Cardiac Effects of Radiation of Treatment  
of Breast Cancer by Simple Respiratory Maneuvers

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<b>13. ABSTRACT (Maximum 200 Words)</b> The present proposal is aimed at developing a special treatment technique for radiotherapy treatment of left-sided breast cancer patients. This technique is based on the findings that holding one's breast after a deep inspiration can significantly reduce the volume of cardiac tissue in the treatment fields and thus reduce long-term cardiac risks for these patients. Specifically, the grant is for developing 1) a patient posture and position monitoring system based on infrared tracking technology to ensure treatment accuracy and therefore to maximize the benefit of the technique and 2) a special breast simulation tool to promptly and accurately evaluate the benefit of this technique for a particular patient. Both developments have been completed. Tests on phantom and radiation therapy patient volunteers have shown that the patient posture and position system is accurate, efficient, and practical as a routine clinical tool. However, it was found that patients occasionally deviate significantly from their normal breath-holding patterns that could affect the treatment accuracy. New patient visual feedback component is added to the system and remains to be tested on patients.				
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## IV. INTRODUCTION

### 1. CLINICAL PROBLEM, BACKGROUND AND HYPOTHESIS

Grant DAMD17-99-1-9084 supports the development of a new radiation therapy treatment technique for left-sided breast cancer patients. The new technique uses simple respiratory maneuvers to reduce radiation to cardiac tissues to avoid possible late cardiac effects. Specifically the grant supports the development and testing of a patient position monitoring system, which will ensure that the radiation treatment is delivered accurately and only when the patient is at the optimal body configuration during the respiratory maneuvers. The grant also supports the development of a treatment planning software that will promptly evaluate quantitatively the benefit of the new treatment technique for a specific patient.

Radiation therapy (RT) plays an important role in patients with early-stage breast cancer both for a) improved quality of life through its use with lumpectomy in providing breast-conserving local therapy and b) possibly improved survival when used as comprehensive local-regional treatment in conjunction with systemic therapy<sup>1</sup>.

An important caveat in considering the effects of local radiation therapy is its toxicity; early reports demonstrated that post-mastectomy RT was associated with an increased cardiac mortality from outdated RT techniques<sup>2-10</sup>. With modern RT techniques, e.g., CT-simulation, cardiac volumes can be delineated more accurately geometrically relative to the radiation field and treatment plans can be more optimized to reduce the radiation to the heart. However, in many cases, the radiation beam still has to traverse a non-negligible portion of the heart in order to treat all of the breast tissue and the concave chestwall to eradicate the residual disease. There is great concern worldwide about the possible late cardiac effects of RT when used in conjunction with cardiotoxic adjuvant chemotherapy. As the incidence of breast cancer increases and the age of the patient population decreases, the issue of late cardiac toxicity will become more important and it is imperative that we search for safer techniques to deliver the radiation treatment.

In the current technique of RT, the patient breathes normally while receiving the radiation treatment. In a recent study of a group of patients, we found that holding breath after a deep inspiration can significantly reduce the cardiac volume in the tangent treatment fields. For many patients, deep inspiration can push cardiac tissues completely out of the treatment fields.

The clinical rationale and hypothesis for this work is that we can develop a treatment technique that delivers the radiation only when the patients hold their breath after a deep inspiration. In a typical first-course breast cancer RT treatment, the radiation dose is given by 22-30 fractions over the period of 4.5 - 6 weeks. On each day, the treatment uses two tangent fields, the medial tangent field and the lateral tangent field, to deliver the radiation. For each beam, the actual time receiving the radiation is about 20-30 seconds, depending on the prescribed dose and/or the patient's anatomy. From our experience with the breath-holding study mentioned above, we found that patients can hold their breath for 20 seconds without any difficulty. If we use 10 seconds of the 15-20 seconds breath-holding duration to deliver the radiation, it only requires 2-3 breath-holding cycles to deliver the total radiation required for each beam. Fig. 1 illustrates the treatment time sequence for one breath-holding cycle.

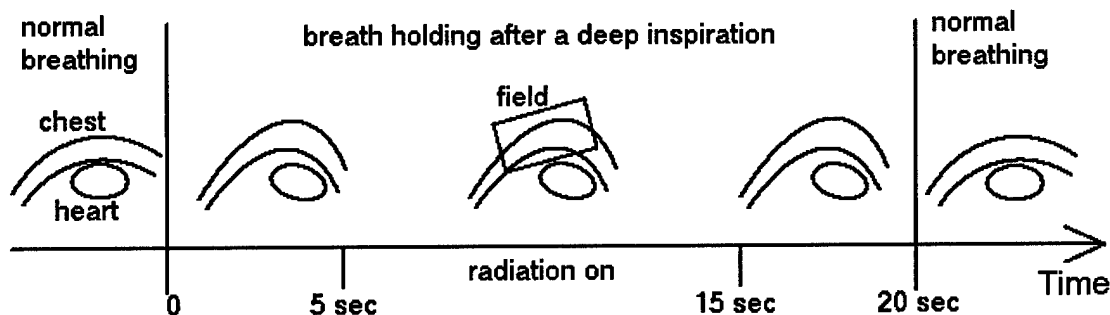


Fig. 1. Treatment time sequence for one breath-holding cycle.

## 2. SPECIFIC RESEARCH OBJECTIVES

### 2.1 Patient position monitoring system

In order for the patient to receive the radiation treatment to the exact anatomical location as planned, it is important that the patient's body position is the same from the treatment planning facility, i.e., the CT-simulator, to the treatment linear accelerator, from one breath-holding cycle to the next, from one treatment beam configuration to another beam, and from one day to another day throughout the whole treatment course of 22-30 days. This requires a monitoring system that can instantaneously track the patient's breath-holding state. Such a system can be developed using a computer interfacing with a three-dimensional (3D) digitization device, for example, the POLARIS system that uses infrared light to track instantaneously the position of infrared reflective markers in space. By placing these markers on the patient's chest and tracking the three-dimensional coordinates of the spheres, one can monitor the motion of any point on the patient's chest with sub-millimeter accuracy.

The development of this patient position/posture monitoring system involves 1) the development of a software interface between the POLARIS system and the host computer, 2) the development of tools for capturing patient body configuration information, 3) the testing of the accuracy and active volume of the POLARIS system and the reflective markers in CT simulator and linear accelerator treatment facilities, 4) the development of software for the calibration of the tracking system to the coordinate system of the facilities (CT-simulation/treatment linear accelerator), 5) the development of the a software for tracking markers placed on patients and evaluating if the patient entered the breath holding configuration for treatment, 6) the testing of tracking system by phantoms, and finally 7) the testing of the system on real patients.

### 2.2 Special functions in treatment planning software

The breath-holding treatment method requires special treatment planning functions that are not available in current commercial CT-simulation/treatment planning software systems. These include 1) the accurate and rapid calculation of the cardiac volume in the field at the CT simulation for both the normal-breathing and breath-holding configuration to determine if the breath-holding treatment technique is necessary for a specific patient, 2) automated or semi-automated field placement procedure for tangential fields with full field matching to allow the planner to rapidly evaluate different treatment geometries, 3) accurate dosimetric corrections for the extremely low lung density due to deep inspiration, 4) convenient interface with the patient position/posture monitoring system.

## **V. BODY OF FINAL REPORT**

### **OVERALL PROGRESS**

The project has two main technical objectives. The first involves the development of an accurate patient body position and posture monitoring system to guarantee that the patient receives the radiation treatment only when they are in exactly the same breath-holding state as planned and throughout the whole treatment course. Specifically, it includes, as described in Statement of Works, the software and hardware development for the system (task 1a), phantom testing at simulation and treatment facility (task 2a), patient testing but without actual radiation beam (task 3), and patient testing with radiation beam (task 4). At the end of the funding period plus the approved extensions, tasks 1-3 have been completed, but task 4 cannot proceed due to the finding that while the position monitoring system is accurate and reliable, the patients cannot always control and reproduce their breath-holding configuration reliably, as detailed below. As a result, a visual feedback function is added to the system and additional non-invasive (without real radiation beam) patient testing is required before proceeding to task 4.

Significant efforts have also been made in improving the infrared reflective markers to be used in tracking changes of patient's body configuration. We have evaluated the accuracy of a hemispherical marker produced experimentally by Northern Digital Inc. These hemispherical markers can be more accurate in tracking the position of a point on the patient's skin surface than the whole-sphere markers originally considered, because the center of the hemisphere can be placed exactly at the point to be tracked. However, markers made by Northern Digital Inc. have a diameter of 12 mm and are not transparent. It is actually quite difficult to place the markers on a soft skin surface such that the center of the marker is exactly at the point to be monitored. It was found that variations between placements could be as large as 3 mm. As a result, we have to produce our own markers that are 6 mm in diameter for phantom and patient testing.

The second goal of the project involves the development of treatment planning functions/tools that are essential for the use of the breath-holding treatment technique. These include the prompt calculation of the cardiac volumes in the field at the time of CT-simulation, so that the benefit of the breath-holding treatment technique can be quantitatively evaluated for a specific patient. Also important is the function to automate or semi-automate the placement of the tangential fields for an optimal beam geometry in terms of minimizing the cardiac and lung volumes in the field. It is essential that functions can be performed rapidly at the time of simulation, since for some patients, the current treatment technique of normal breathing may work just as well, and there is no need to pursue the breath-holding treatment with additional work and unnecessary CT scans.

Originally, we plan to implement these special functions in an existing CT-simulation software. However, we could not find a commercial CT-simulation software company that is willing to collaborate on this. As a result, we had to develop an independent software tool (Breast Simulation Tool). This tool can work hand in hand with a CT-simulation software (Advantage-Sim, General Electric) and perform the essential function of computing the cardiac volume in the field and placing the tangent fields semi-automatically. It also has the function to capture the coordinates of marker points from the CT-scans. These coordinates will be used in the patient position monitoring system. Although less than ideal, it is, however, a workable system and has all the functions specified in the original plan.

## **SPECIFIC PROGRESS**

### **Patient Posture and Position Monitoring System**

The main components of the system include an infrared tracking camera system (Polaris, produced by Northern Digital Inc.), a computer with windows operating system 9x/NT/Win2000, and retro-reflective markers that can be placed accurately on patient's body surface. The camera system can shine infrared lights in the active tracking volume, receive the reflected light from the markers, and then calculate their locations in three-dimensional coordinates. These coordinates are sent to the computer where a program performs the proper coordinate transformation, capture, record and/or compare the marker positions. When the markers are placed on patient body surface at critical points, e.g., at midline on the chest, planned treatment field entry points, etc., the patient's body posture and position are determined in relation to the radiation field. By recording these markers positions at simulation and reproduce their positions at treatment facility during each treatment, we can guarantee that the patients receive treatment in the same body configuration as planned and thus reliably receive the maximum benefit of the respiratory maneuver. The program is developed using Visual Basic 6.0. The program also interacts with a database created to store and browse patient's data. The database resides a network server so that the data can be accessed both at CT-simulation facility and treatment facility. The system is described below.

#### **A. System Installation**

The position control system has been installed both at CT-simulation (Fig. 2) and at a treatment unit (Fig. 3). Two sets of monitors and keyboards are used for the computer so that it can be controlled at both inside and outside of the procedure room.

#### **B. Software components**

##### **a) Coordinate calibration.**

A software program has been developed to calibrate the camera coordinate system relative to the coordinate system of CT-simulation and linear accelerator treatment room (Fig. 4). The program establishes the coordinate transformation from the camera system to the room coordinate system to be used by the patient position monitoring system. The calibration is to be checked routinely to verify that the position of the camera has not been changed.

##### **b) Patient information organizer.**

The program (Fig. 5) organizes the geometric information for a specific patient, e.g., the treatment field geometry, the position of the tattooed points, and the points to be monitored by the infrared camera system, etc. This program will allow one to assemble all the information from different sources, e.g., CT-simulation software, patient monitoring system in the CT-simulator, etc., together to produce a file that will be used by the patient monitoring system in the treatment room.

##### **c) Patient body posture and position control**

Fig. 6 shows the main user interface for body posture and position control. This is a screen capture of the replay of a recorded session where a patient performed a breath-holding exercise. Eight markers were used with seven on the chest and one on the left elbow to ensure the patient left arm is positioned properly. The right upper view shows the anterior-posterior projection of the marker positions, where the cyan-colored crosses represent the present position of the markers as tracked by the

infrared camera, while the ellipsoids (very small) indicate the position of the markers captured at the CT-simulation as the standard. The yellow ellipsoids are for non-field related points, and the pink ellipsoids mark the superior and inferior corners of the medial tangent field. The upper left view shows the beam's eye view for the lateral tangent field where the pink markers are also shown. The lower display plots the instantaneous position of the marker (x, y, or z) as the patient performs the breath holding exercise. The middle panel displays the values of the clinically relevant parameters, e.g., AP Pin, leveling, etc. The left panel shows the instantaneous chest elevation calculated from the marker positions and compared with the expected value with an acceptable range. This panel was added most recently. The intention is to display just the panel on another monitor visible to the patients to give them a visual feedback so that they can control their respiration maneuver better. When all the markers reach the standard positions within the specified threshold, the lower left three panels will turn green, as shown in Fig. 6, to indicate that the patient posture and position are reproduced and the treatment can proceed.

#### d) Database for patient position data

The patient's position monitoring system will generate a large amount of data. For each simulation or treatment session, a patient will undergo several breath holding cycles, and for each cycle, the system will track and store the positions of reflective markers on the patient at a minimum rep rate of 10hz for a period of 20 seconds. Moreover, these data will be generated both at CT-simulator and treatment units. Therefore, it is necessary to have an efficient system to manage the data for multiple patients with multiple treatment sessions and at multiple locations across the network. We created a database using Microsoft Access to store the patient information and all geometric data regarding patient's radiation treatment, i.e., treatment course, fields, body control marker positions, etc. We have developed a browser application to review patient data structures and database interfaces for all the applications relevant to patient body position control. Fig. 7 shows the browser application user interface. The database resides on a Windows NT server and can be accessed by all the applications from all simulation and treatment units through ODBC (Open Data Base Connectivity) database drivers.

### C. Hemispherical reflective markers with smaller diameters

We first contacted Northern Digital Inc., who produced the large hemispherical markers. Unfortunately, the company does not want to investigate any further. To our knowledge, Bioengineering Technology System (BTS) is the only company that produced hemispherical markers with smaller diameters, e.g.,  $< 5$  mm. We have obtained a few of such markers and found that they are workable as far as tracking is concerned. However, unlike the hemispherical markers made by Northern Digital Inc that is hollow, the base of these hemispherical markers are solid and are made of rubber-like material. This could potentially increase the radiation dose to the patient skin surface at the points where the markers are placed, if the markers happen to be in the treatment field, a situation that cannot always be avoided. Moreover, the quality of the reflective coatings on these markers is not consistent and they do not always cover the side area well. When the markers are at an angle from the infrared camera, as is always the case when the markers are placed on the patient's chest, tracking can be severely affected. It was concluded that these markers were inappropriate for the project.

By using plastic sheets and thermal expansion, we were able to make hemispherical shell shapes with a diameter of only 6 mm. We then applied adhesive tapes with reflective coating on the hemispherical plastic shape. It is found that these smaller markers are more accurate in placement and since it is hollow, it will not significantly increase the radiation dose to the patient skin surface. However, the process of making these markers is all manual and very time consuming. Nevertheless, we were able to make sufficient number of markers to complete the patient testing. Fig. 8 shows a few of



these markers. A plastic base with a long handle is attached to the marker for easy handling.

#### **D. Phantom Testing**

##### **a) System accuracy test at CT-simulator**

A breast phantom was used to conduct the test. Eight markers were placed on the phantom as shown in Fig. 9 to track seven points on the phantom (The two close markers are used to track a single point, which is required by the marker recognition method used in the system.) The hemispherical markers have a radio-opaque bee-bee at the center of its base. These bee-bees are visible in the CT images and their positions can be obtained accurately. (The transverse coordinates, i.e., left-right and anterior-posterior, are obtained from axial CT images, while the longitudinal positions, i.e., superior-inferior, are obtained from scout images to avoid errors introduced by the finite spacing between axial images.) Since the markers are hemispherical and the bee-bees are at the center of the hemisphere, the marker positions captured by the patient position control system should agree with the positions of the bee-bees obtained from the CT-scan. Table 1 shows the differences between the two. The maximum difference is 1.5 mm, while the average over all the points is less than 0.6 mm. These values are well within the expected accuracy of the system. These results demonstrate that the overall accuracy of the system, including calibration, coordinate transformation, marker preparation, etc., is satisfactory.

##### **b) Motion tracking**

To evaluate the ability of the system to monitor changes in patient's posture or position, we used a phantom that can generate a periodic motion. The periodicity is set to 6 seconds with an amplitude  $\pm 1$  cm. This motion simulates closely the patient's motion due to regular breathing. A couple of markers are placed on the phantom and their position changes were monitored by the system. Fig. 10 shows the software interface at the time of the testing. The graph at the bottom of the screen shows the periodic change in one coordinate. At the rep rate set at 10Hz, the system can accurately track the change in marker positions. Naturally, the higher the rep rate, the more sensitive the system can be. However, the limit for the rep rate is determined by the number of markers the system has to track at the same time, and ultimately determined by the CPU speed of the computer.

#### **E. Testing on radiation therapy patients**

##### **a) Purpose**

The test will evaluate the performance and clinical applicability of the patient position monitoring system on real radiation therapy patients. This includes the qualities of the reflective markers, the manner and time it requires to accurately place them on the patients, the software user interface, the efficiency in tracking, recording, saving and comparing marker positions, the database system, and all the other issues that are important for a routine clinical system. Another major objective is to evaluate how patients, particularly radiation therapy patients, perform breath-holding exercises, in terms of duration, reproducibility, and consistency throughout the treatment course.

##### **b) Protocol**

A protocol has been approved by Dana Farber Cancer Institute where the test was conducted (A Preliminary Evaluation of a Patient Position Monitoring System for Using Respiratory Maneuvers in Radiation Therapy Treatment of Left Breast Cancer Patients to Avoid Possible Late Cardiac Effects, IRB#1999-P-010427/5, Dana Farber Cancer institute Legacy #99-180). Six patients have been recruited and tested during the period from October, 2002 to January, 2003. These are left-sided breast cancer patients receiving radiation therapy treatment.

### c) Testing Method

Eleven testing sessions were conducted for each patient, one at the time of CT-simulation and others at treatment unit throughout the treatment course. The tests were performed after their routine clinical procedure and therefore brought no interference to their treatments. The testing proceeds as follows. After the patient has finished the routine treatment, reflective markers were placed on their chest. A quiet respiration body configuration is first recorded over the course of 30 seconds. Then the patient was asked to take a deep breath and hold it for 20 seconds while the system tracks and records the marker positions. The breath-holding cycle is repeated for four times. Two of the sessions were conducted near the end of the treatment course in order to find any effect by the radiation treatment. The marker positions on patient's skin surface were initially determined at CT-simulation and were marked either by tattoo or by a special type of ink invisible under room light but visible under a special blue light lamp.

### d) Data Processing

The averages of body configuration parameters, i.e., chest elevation, sternum angle, superior leveling, inferior leveling, superior-inferior alignment, are calculated for each breath-holding exercise and compared over each session and/or between different sessions.

### e) Results

The patient monitoring system performed very well. The markers can be placed easily and accurately on the patients, and tracked by the camera without any difficulties. The software worked efficiently in capturing, displaying and recording the marker positions and calculating the configuration parameters. All patients performed exercises without any difficulties. There was no sign of fatigue at the end of the exercises for any patient. No patient had any complaint about placing the markers on their chest. Overall, the procedures proceeded very well throughout the tests. The entire testing procedure from marker placement to marker removal can be completed within 3 minutes.

## F. Patient data analysis and discussion

### a) Diverse breath-holding pattern for different patients

The data showed significant variations between patients in their breath-holding performances. Fig. 11 plots the chest elevation as functions of time (milliseconds) for two patients (A and B) for both a breath-holding exercise (pink) and a period of quiet respiration (blue). Patient A gave a very deep and also very stable breath-hold. During the intended treatment period, i.e., the middle 10 seconds of the breath holding (the 10-20 second section in the plots), the chest elevation is 2.3 cm and the variation was less than 1 mm. Patient B, on the other hand, gave a very shallow and very unstable breath holding. The maximum elevation during the treatment period was only 7 mm at the beginning and kept decreasing to 5 mm at the end. This patient also had very unstable quiet respiration; the variation is as large as 5 mm, almost comparable to her breath-holding chest elevation. This indicates that patient B is very unlikely to receive significant benefit from the breath-holding method for her breast cancer treatment.

### b) Diverse reproducibility between patients

Fig. 12 shows for two patients the average chest elevations over all the exercises spread throughout the whole treatment course. Patient A generally showed small variations during each session and over the whole course the average decreased by 3-4 mm. Such changes may be acceptable without re-planning the treatment, considering the generally accepted tolerance of 5 mm during treatment with

the current treatment technique of quiet respiration. Patient B had much large variations in some sessions and very small variations in others. But, over time, patient B significantly increased the average chest elevation. The total change is as large as 8 mm. Change of this magnitude definitely requires re-planning of the treatment.

#### c) Large random variations

Although patient A in Fig. 12 generally showed stable performances, but on some days, significant changes. For example, one of the exercises during the eighth session gave a very low chest elevation. Fig. 13 shows the averages of chest elevation for all 48 exercises for another patient. During most of the exercises, the chest elevation stayed within 2mm of the average value, acceptable in terms of treatment accuracy. However, for exercises 16, 24, and 36, large deviation occurred. These unexpected excursions happened for every patient with different magnitude.

#### d) Discussion

The significant patient-to-patient variations in terms of chest elevation and breath-holding pattern were not surprising. In fact, it reiterated the need for developing the patient posture and position monitoring system in the first place. With this system we can perform tests on patients to evaluate and determine the eligibility for breath-holding treatment, and/or to customize for a particular patient the position and length of the treatment period during her breath-holding cycle.

The large random variations for the same patient, on the other hand, are somewhat surprising. During the tests, we instructed the patients to take the inspiration as deep as possible before holding the breath, in hoping that the deepest may be the most consistent. Also, in our original CT study<sup>11</sup> where we scanned the same patient twice sequentially, we did not find any significant variations between the breath-holding patterns for the same patient for any of the 15 patients. In the present study, however, the large random variation occurred for every patient at some time in time, including the best and most consistent performer. Apparently, the deepest does not automatically ensure the consistency.

In principle, this problem can be dealt with by setting a limit on the magnitude of variations in chest elevation in the position monitoring system so that once the variation is beyond the acceptable range, the radiation beam is automatically shut off. However, such an approach would be too stressful for patients, as well as for operators, and is thus impractical as routine clinical procedure.

A more sensible approach would be to provide to patients a feedback signal, preferably a visual feedback, so that they can try to adjust their breath-holding effort consciously. Fig. 14 shows a panel display that we recently added to the position monitoring system. The cyan-colored bar in the center indicates the instantaneous value for the chest elevation of the patient during a breath-holding cycle and the green area mark the standard range that the patient should try to reach and remain in. This view is shown to the patient through a separate monitor mounted on the ceiling of the treatment room. The standard range can be determined by performing a sufficient number of breath-holding exercises before hand and then used for the CT-simulation and for the whole treatment course. A breath-holding training for the patient may also help.

A recent report described a breath-holding treatment method for left-side breast cancer patients.<sup>12</sup> An active breathing coordinator (ABC) device was used to control patient's breath-holding maneuvers by suspending breathing at a defined lung volume with a nose clip and a valve in a mouthpiece. The treatment accuracy was verified by portal imaging. This shows that some type of breathing control is necessary.

Compared to our method where patients perform respiratory maneuver without any external control, the ABC system has an advantage that it can force the patient to hold the breath and prevent uncontrolled relaxation. However, its main disadvantage, besides the uncomfortable nose clip, is that the ABC system can only provide an indirect control over the accuracy of the treatment, since the same lung volume may not always guarantee the same chest wall position. Although portal images are the ultimate verification for the treatments, they are nevertheless always after the fact. Our method, on the other hand, directly monitors the chest wall position and also can evaluate and eliminate potential accuracy issue before radiation beam is turned on.

### **Special treatment planning tool for breast cancer treatment**

Breast simulation tool (BST) works hand in hand with the CT-simulation software Advantage-Sim (General Electric). It can rapidly calculate the lung and heart volume in the tangent field. It also generate tangent field pairs based on the input of a few clinically relevant points, e.g., medial field border, lateral field border, etc., entered simply by a mouse click on the transverse CT display. Then the program can automatically produce a macro file that can in turn be used the CT-simulation software to automatically setup the tangent field pairs. Fig. 15 shows the breast simulation panel with the volume of lung and heart in the field. Fig. 16 shows the operator environment for CT-simulation using breast simulation tool.



Fig. 2. System installation at CT-simulator.

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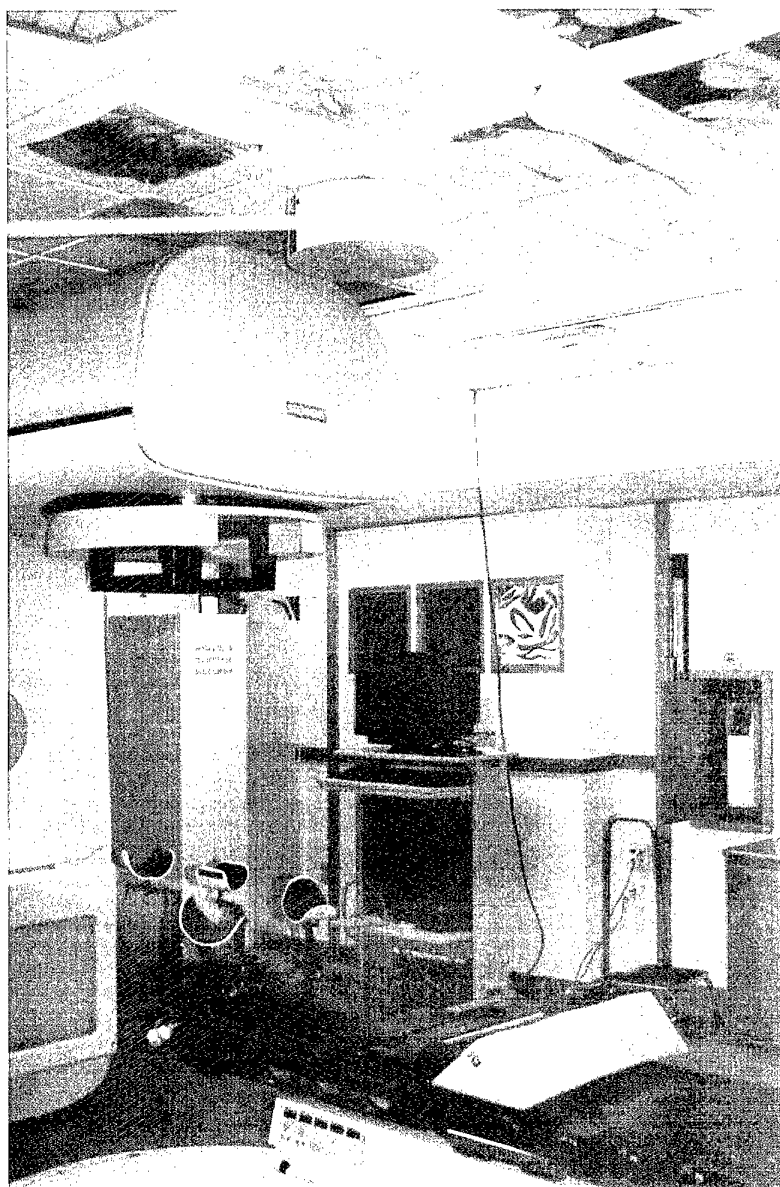


Fig. 3. System installation in treatment room.

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Calibration

O

old O =  
new O =  
Diff. =  
Std =

x

y

z

distance

Average 50

Quit

P

old P =  
new P =  
Diff. =  
Std =

Q

old Q =  
new Q =  
Diff. =  
Std =

Errors

Standard

Last calibration

New calibration

OP

OQ

A

Fig. 4. User interface for calibrating the coordinate system of the POLARIS camera system the room coordinate system of the CT-simulator or the treatment linear accelerator.

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15

Patient Data Structure Builder  
File Import Tools

Patient Name: Test, Patient Patient ID:

Plan Name: Resim - RT For: RT Site: Left Breast Tech: Tangent Only

Fields Structures

1 Patient Setup  
1 med  
1 lat

Name: 1 med

Shift X	Shift Y	Shift Z
9.74	2.25	13.20

Gantry	Coll	Table
308.0	18.0	0.0

Width	Y2	Flength
13.0	10.5	21.0

X1	Y1	X2	Y2
6.5	10.5	6.5	10.5

Activity Location:  
CT-SIM  
CONV-SIM  
D10DFCI  
OTHER

Images:

Tattoos:

Med. Cent. Entrance  
Med. Sup. Corner  
Med. Inf. Corner

Tattoo Locations:

Field Center  
X1 Center  
X2 Center  
Y1 Center

Reduced Position:  
x: -1.00 y: 0.00

Name: Med. Cent. Entrance

Image Tattoos Markers

Tools:

Setup:

Setup

Configs:

Default

Name: Default

Posture Control Method:  
Breast Setup Full Select

Fid Markers:

Center  
Superior Left  
Superior Right  
Inferior Left  
Inferior Right  
Left Elbow  
Superior Corner  
Inferior Corner

Name: Center

MarkerPosition:  
x: -13.5 y: 0.3 z: 2.9

Base Tolerance:  
x: 0.1 y: 0.1 z: 0.1

Tolerance:  
x: 0.3 y: 0.4 z: 0.5

Fig. 5. Patient information organizer. It contains the treatment fields (left area), the list of field border tattoos in the beam's eye view (middle area), and the control points including patient posture control point, as well as field related points.

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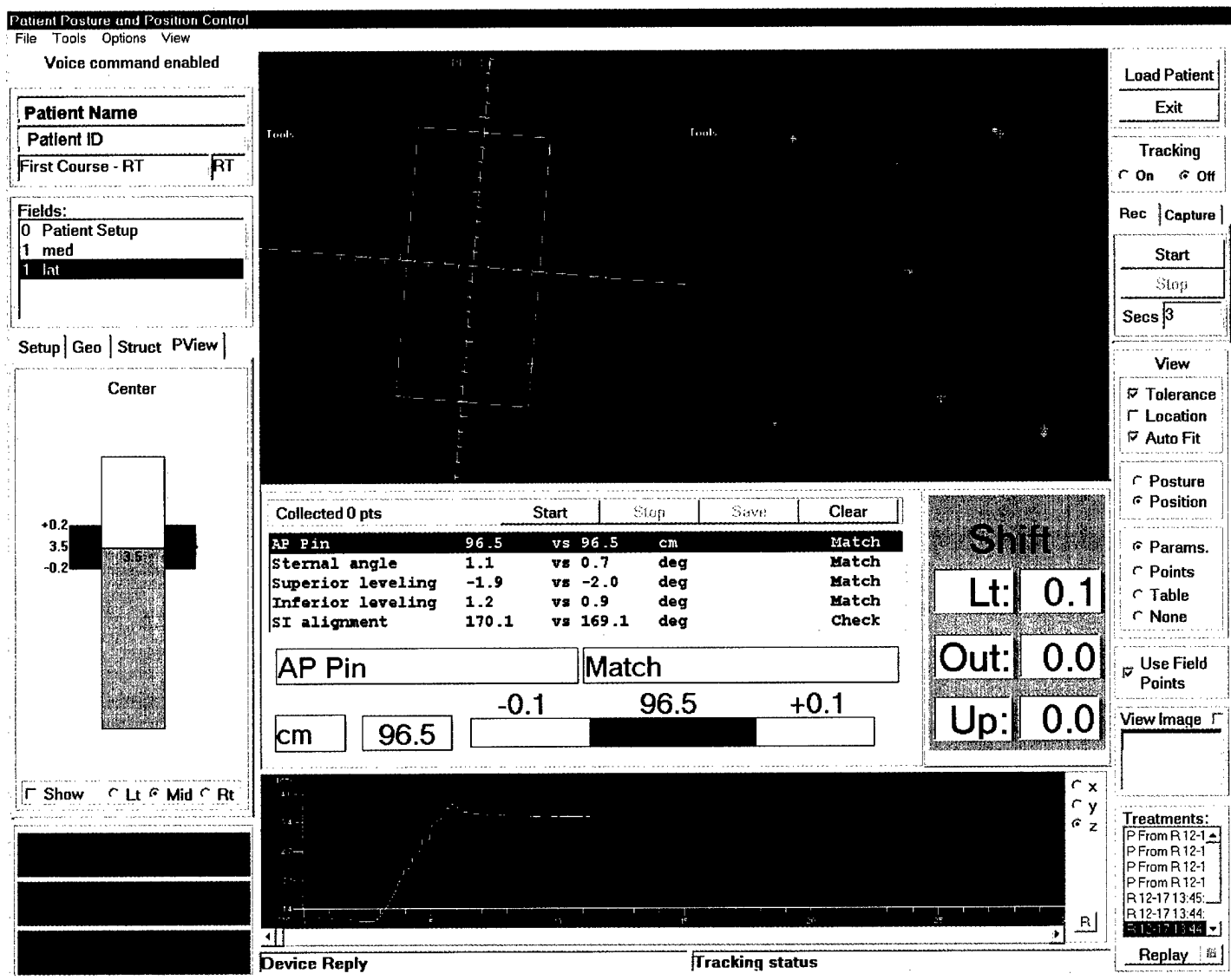


Fig. 6. Main user interface for patient body posture and position control.



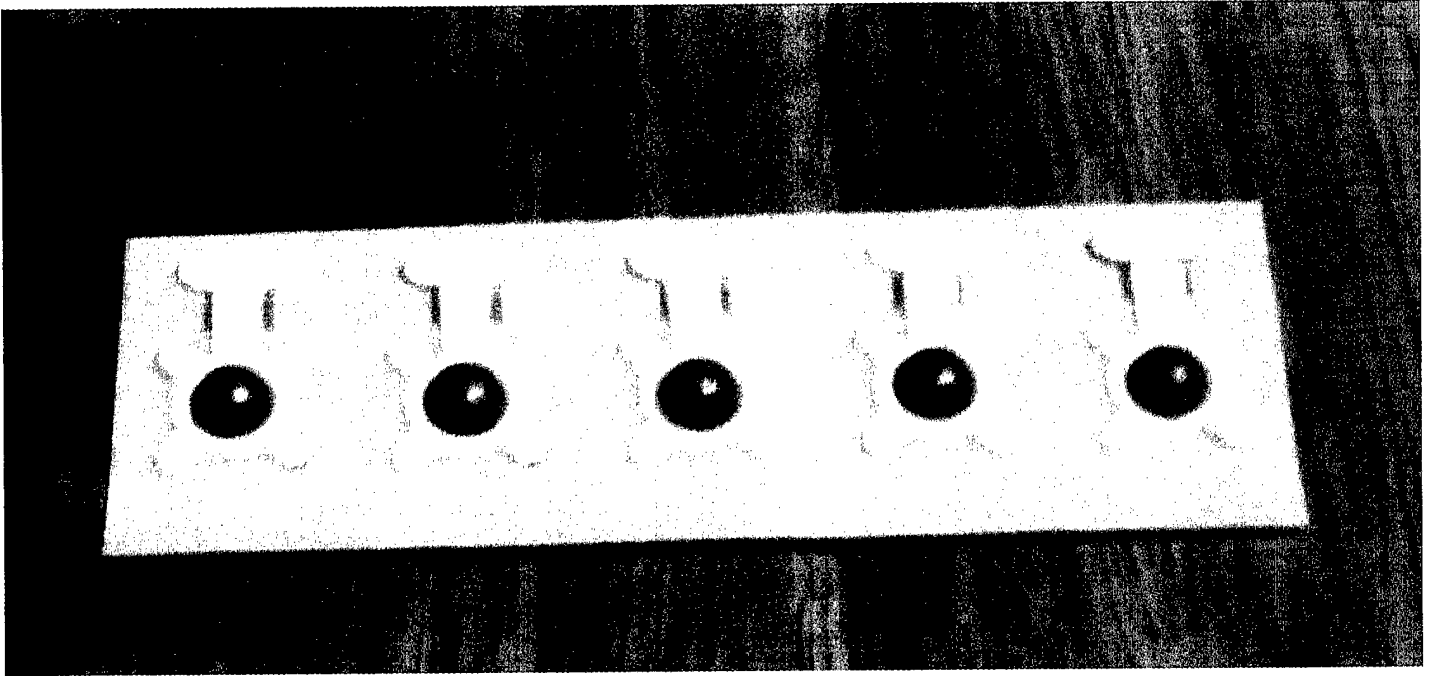


Fig. 8. Reflective markers.

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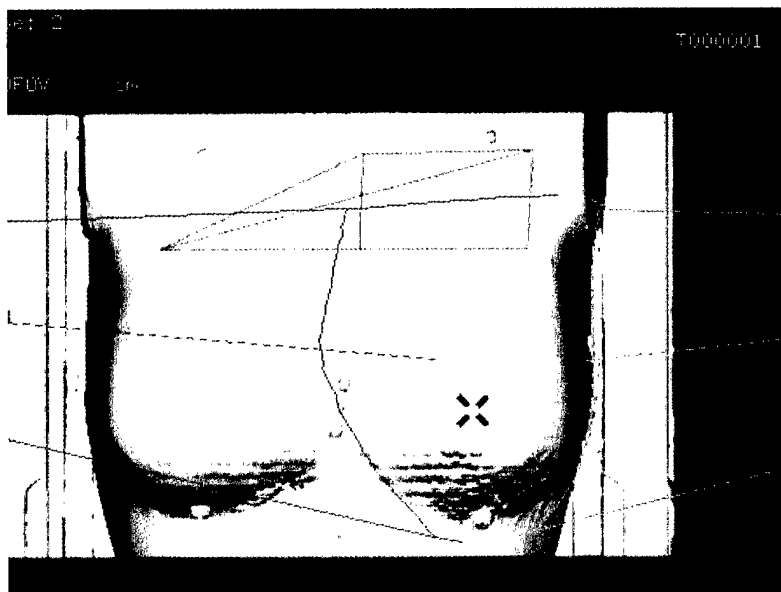


Fig. 9a. 3D surface reconstruction of the breast phantom used in testing the accuracy of the patient position system at CT-simulator. Eight markers are placed on the phantom for tracking the seven points.

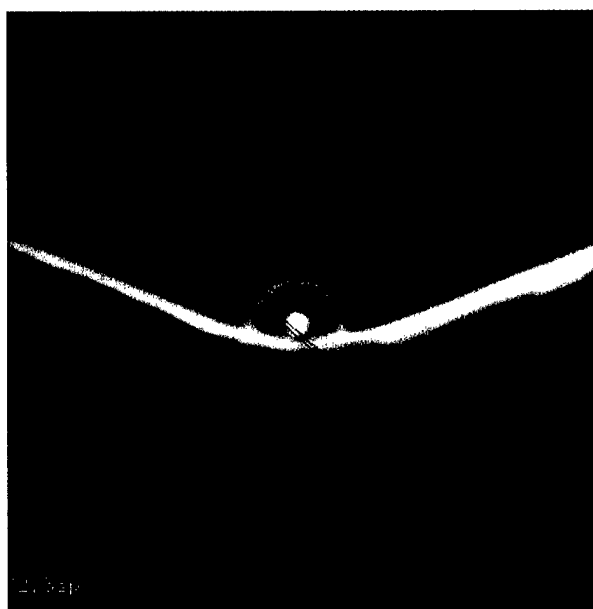


Fig. 9b. Transverse view of the hemispherical marker. By placing a lead bee-bee at the center of the hemisphere, we can obtain the coordinate of the points to be monitored in the CT and compare it with the coordinates captured by the infrared system.

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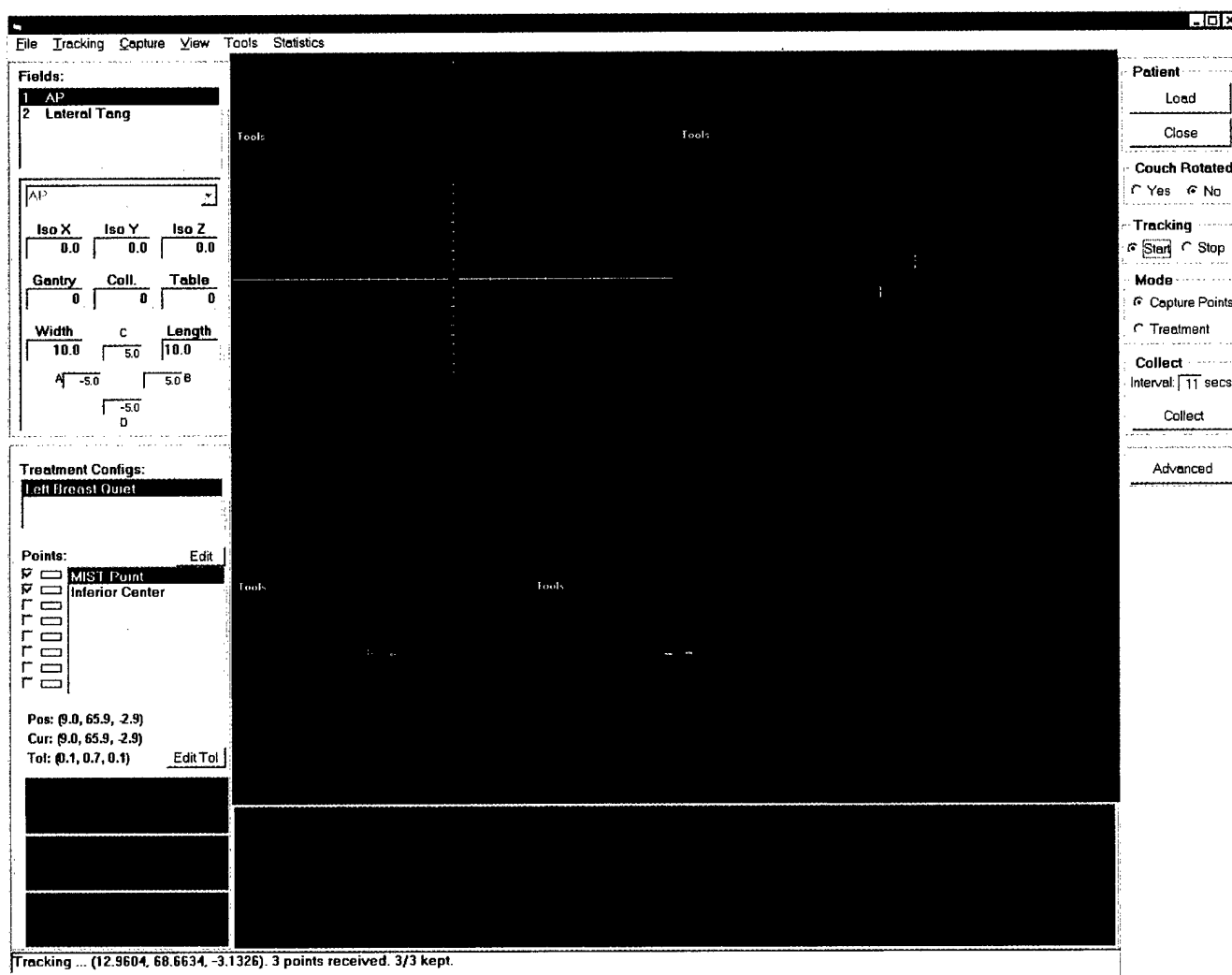
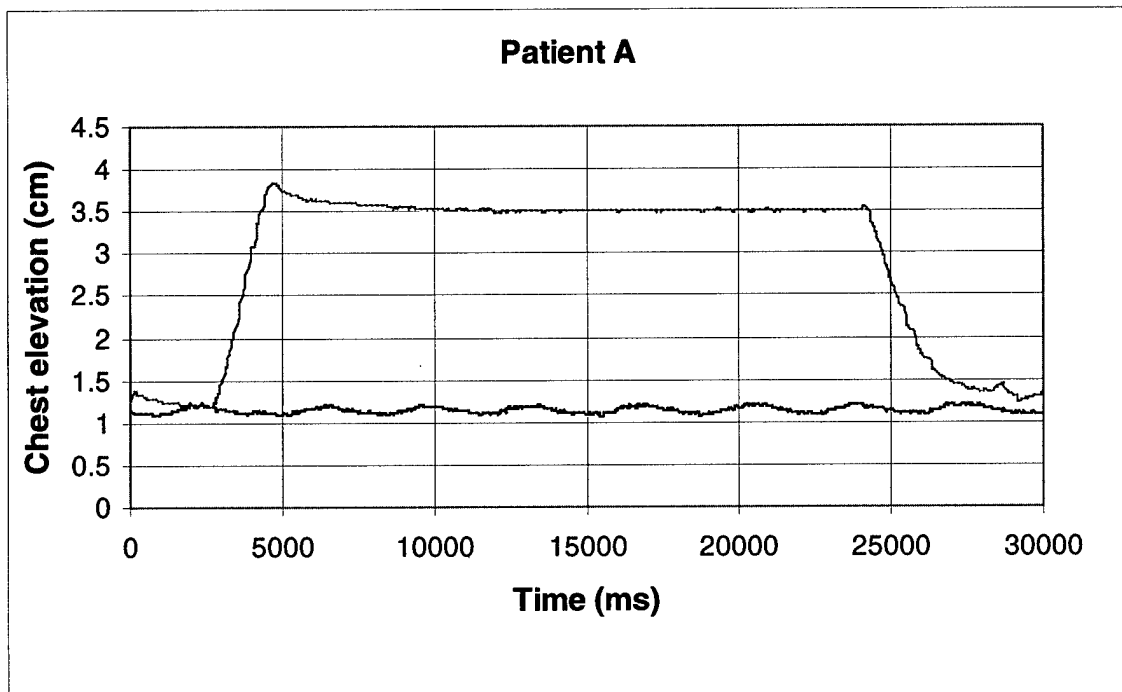
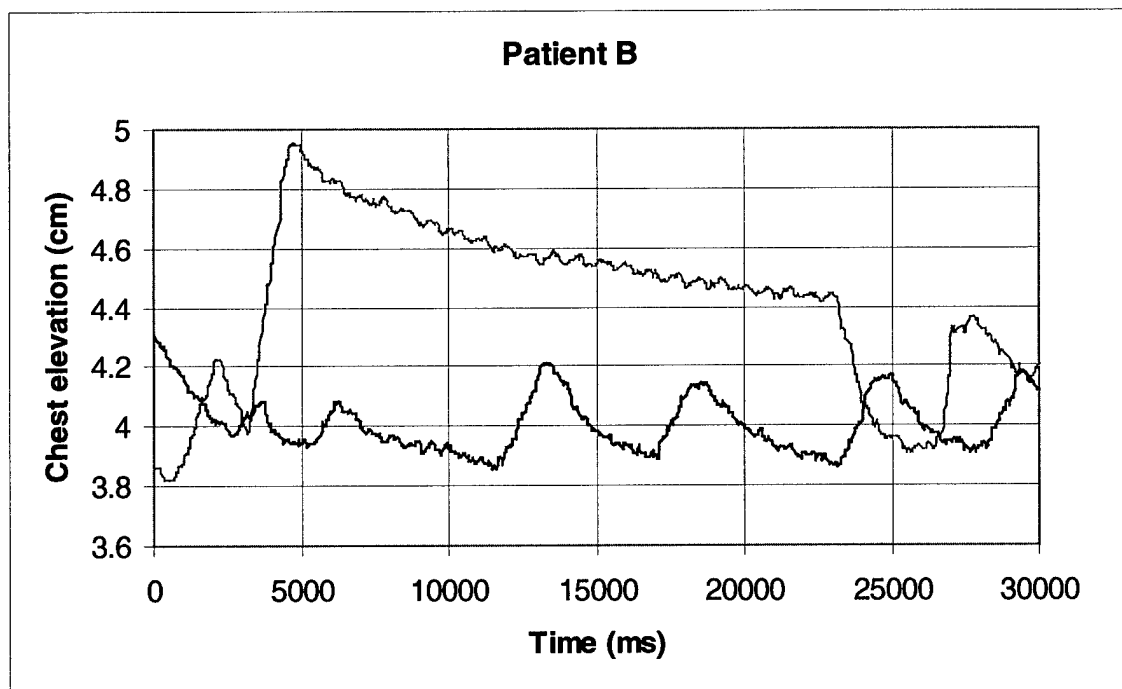


Fig. 10. User interface for the motion tracking test.

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(a)



(b)

Fig. 11. Chest elevation variation as a function of time during a single breath-holding exercise for two patients, (a) and (b), respectively. The blue line is for quiet respiration while the pink lines are for breath holding.

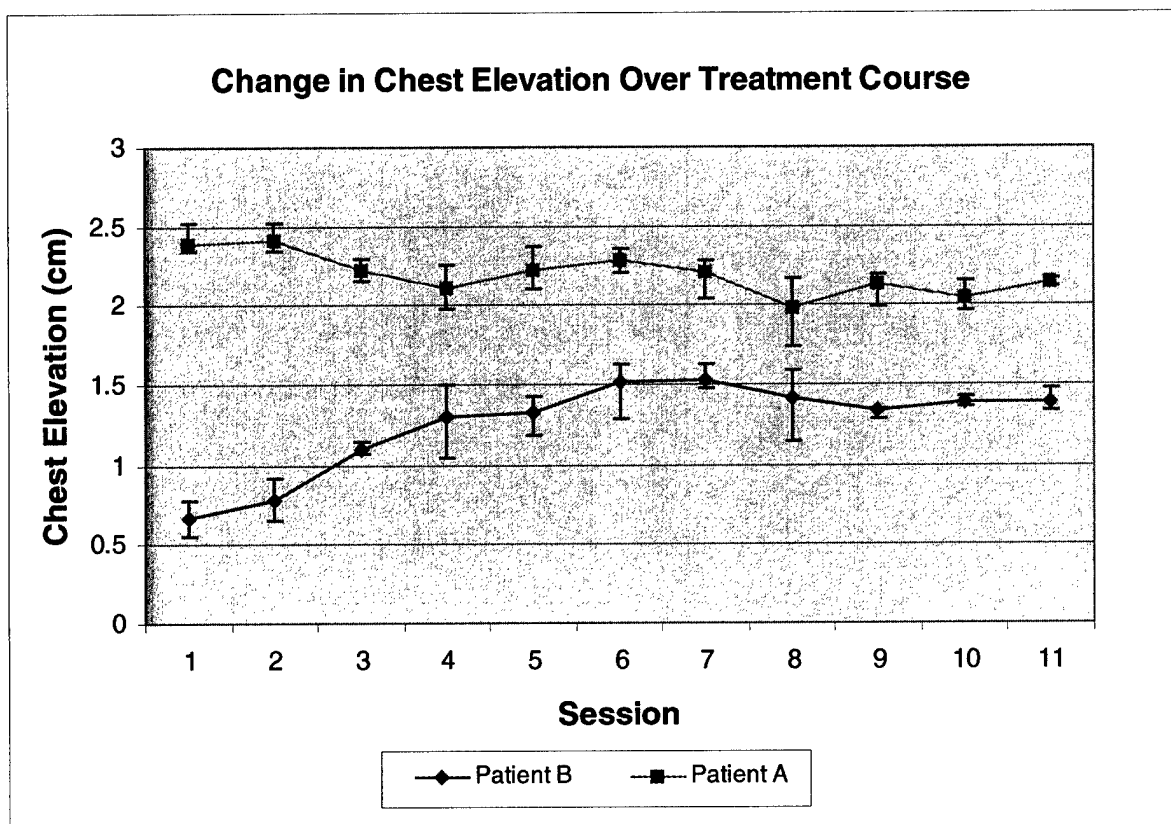


Fig. 12. Change in average breath-holding chest elevations over treatment course for patient A (pink) and B (blue). Plotted is the average over the average elevation for each of the four exercises during each session. The error bars indicate the maximum and minimum for four averages for each session.

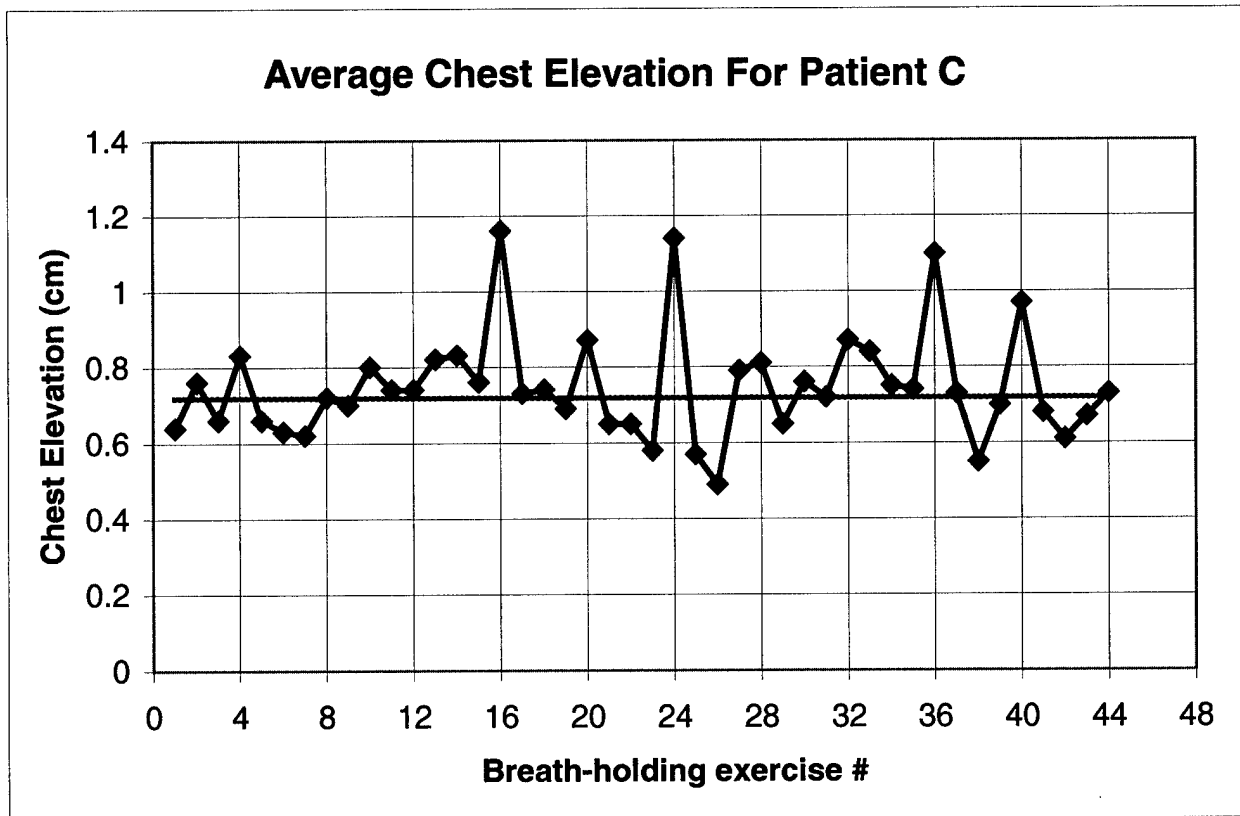


Fig. 13. Average chest elevation during all 48 breath-holding exercises for patient C. The average of these values (not including 16, 24 and 36) is also shown (pink).



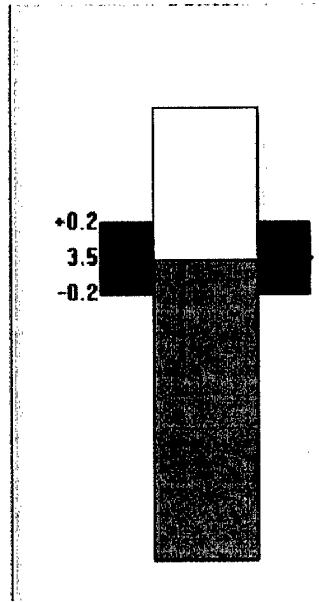


Fig. 14. Patient chest elevation feedback display. The cyan-colored bar in the center shows the instantaneous chest elevation during the respiratory maneuver. The green area marks the expected chest elevation with acceptable margins. During the breath holding, the patient will adjust her effort to reach and remain in the green area. The numbers are display only for the operators. For patients, the display is shown on a separate monitor mounted on the ceiling of the treatment room and the numbers are omitted to avoid confusion.

<input checked="" type="radio"/> Tangent Only		<input checked="" type="radio"/> 3-Field	
<div> </div>			
	R (mm)	A (mm)	S (mm)
Med Bd	-0.5	119.5	10.0
Lat Bd	-173.0	-0.5	10
Point	75.0	0.0	
Apex	-132.7	128.9	
<div> </div>			
Isocenter	-120.5	108.1	10.0
To Iso	-120.5	108.3	Gray
Type-in	0	0	Color
Point	0.0	0.0	
To Pt			
Point 1	159.4	37.5	Point 2
D (mm)	226.0 (mm)	Angle	117.4 (deg)
		XV	Quit

- Left -

Field Width = 11.6 cm Flash = 3.3 cm

CLD = 2.0 cm MLD = 2.1 cm

lungs 8.4% ( 87.7 cc/ 1045.2 cc)

heart in field by 1.5 cm

heart 6.0% ( 18.5 cc/ 306.1 cc)

Point in field = 14.1 cm

Pin = 98.9 cm Dist = 12.0 cm

Sep = 21.0 cm CW = 235.2 deg

Load contour	Unload contour
FLength 22	22.0 GE plan
Med Beam Angle	Lat Beam Angle
Gantry 301	Gantry 128
Coll 12	Coll 348

Setup Pt 13.6 124.2

Pin = 98.4 cm Dist = 13.4 cm

Sep = 22.4 cm CW = 236.2 deg

Fig. 15. Breast simulation tool. It shows the volume of lung and heart included in the tangential field pair.

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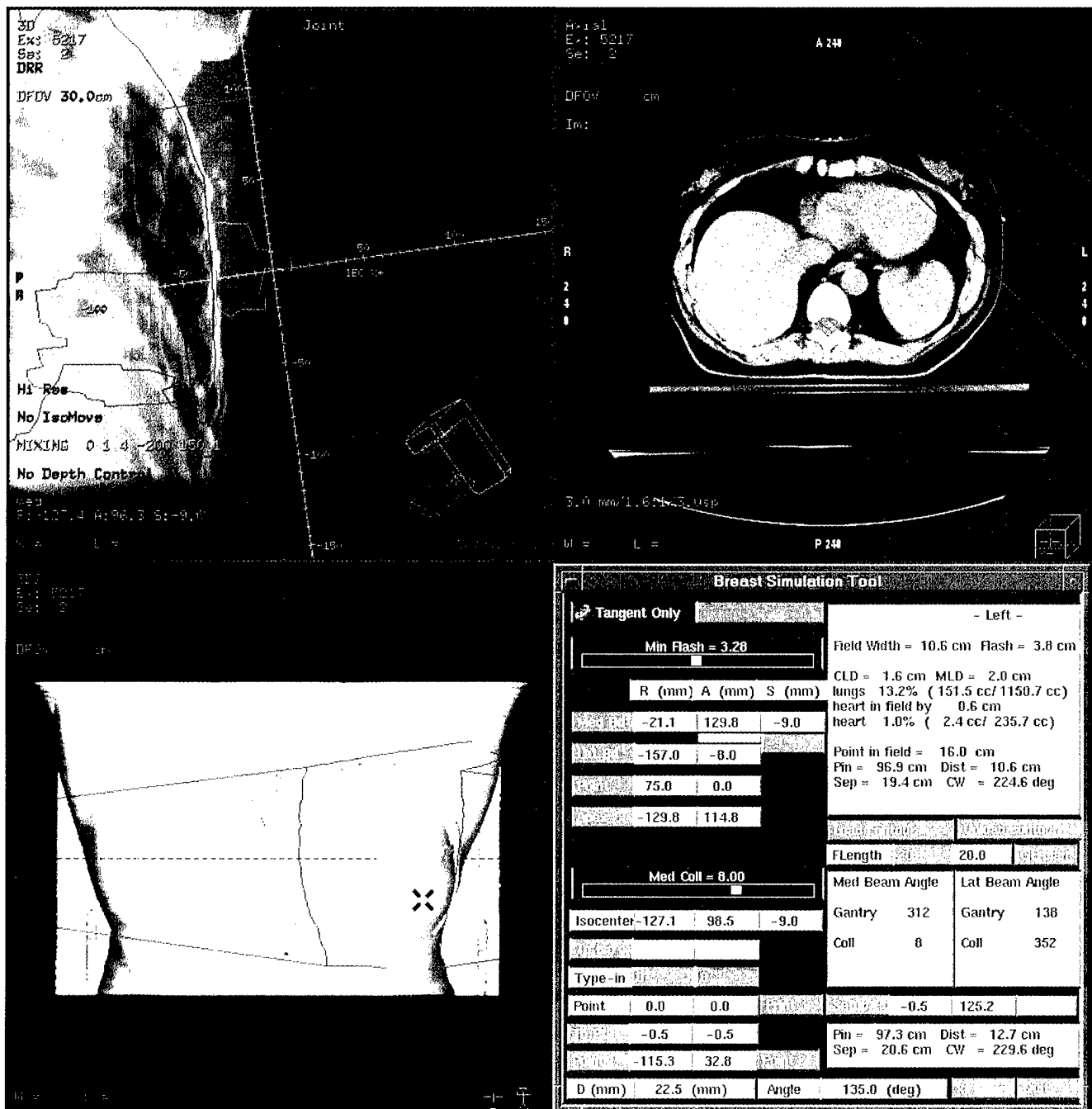


Fig. 16. User interface during CT-simulation of breast cancer treatment using breast simulation tool.

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Table 1. Differences in coordinates (mm) between captured marker positions and those obtained from CT. RAS is the internal coordinate system of the CT images. The R and A coordinates were obtained from the axial images. The S coordinates were obtained from a frontal scout view to avoid errors introduced by the finite spacing between adjacent axial images.

For Test01, Test T000001

	Mist	Inf. Cent	LT Cent	RT Cent.	LT Sup	RT Sup	Sup Cent	average	max	min
R=	0.30	0.40	0.30	0.10	1.00	0.60	0.10	0.40	1.00	0.10
A=	0.50	1.30	0.00	0.10	1.30	0.80	0.10	0.59	1.30	0.00
S=	0.70	0.20	0.40	0.20	0.70	<b>1.50</b>	0.30	0.57	<b>1.50</b>	0.20

## **VI. KEY RESEARCH ACCOMPLISHMENTS**

The proposed patient posture and position monitoring system based on infrared tracking technology has been developed. Tests on phantoms and patients showed that the system is accurate, robust and convenient to use as a routine clinical tool.

The proposed special breast simulation tool has been developed for promptly evaluating the benefit of breath-holding treatment technique for a particular patient.

## **VII. REPORTABLE OUTCOMES**

A patient position monitoring system for radiation therapy treatment of breast cancer  
By Hsiao-Ming Lu at the AAPM 2000 Annual Meeting, July, 2000, Chicago.

Abstract attached (Appendix A).

## **VIII. CONCLUSIONS**

The main development tasks of the proposal have been completed. These include a special breast simulation tool to allow prompt evaluation of the benefit of the breath-holding treatment method for a particular patient at the time of CT-simulation, and a patient posture and position monitoring system to guarantee the accuracy of such treatments. Tests on phantom and with actual radiation therapy patients have shown that the monitoring system is accurate, robust and convenient to use as a routine clinical tool.

Testing on radiation therapy patient volunteers showed that not only different patients show different characteristics in their breath-holding maneuvers, the same patient can occasionally deviate from her normal performance with the magnitude that could affect the treatment accuracy, even when the patient always tried to take the breath as deep as possible. A visual feedback display was thus added to the system so that the patient can adjust her effort in reproducing the desired breath-holding configuration. Although it remains to be tested on patients, we are confident that with the visual feedback, the reproducibility can be significantly improved and the breath-holding treatment technique can be implemented for real treatment.

We like to point out that the patient posture and position-monitoring system is not exclusively for breath holding breast cancer treatment. In fact, it can be used for any radiation therapy treatments with or without breath holding to improve treatment accuracy.

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## **X. APPENDIX A.**

Abstract for presentation at AAPM Annual meeting, July 2000, Chicago.

### **A patient position monitoring system for radiation therapy treatment of breast cancer**

Hsiao-Ming Lu, Ph.D.

We have developed a patient position monitoring system specifically for breast irradiation using the breath-holding technique. Breath-holding (15-20 seconds) after a deep inspiration can substantially reduce the cardiac volume included in the tangential fields and thus reduces the possible late cardiac toxicity that has raised wide concerns particularly when cardiotoxic chemotherapy is also used. The system consists of a window-based software application interfacing with an infrared camera system that can track three-dimensional positions of infrared reflective markers with sub-millimeter accuracy. When such markers are placed on the patient's chest at points that control the patient's body posture as well as its position relative to the planned radiation fields, the system can accurately and instantaneously monitor the patient's body configuration throughout the breath holding cycle. Only when the patient fully reproduces the same breath holding configuration for which the treatment fields are designed, the system will issue a signal to the operator to turn on the radiation beam. While the treatment is proceeding, the system continues to monitor the patient and will interrupt the treatment if the body configuration changes beyond a specified tolerance. With the system, the patient is guaranteed to be in the same body configuration from CT-simulation to treatment, from field to field, from fraction to fraction throughout the whole treatment course, and thus receive the full benefits of the breath-holding treatment technique.